DESIGN AND MOTION CHARACTERISATION OF FIBRE-REINFORCED SOFT ACTUATOR

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DECLARATION

I declare that this project entitled "Design and Motion Characterisation of Fibre-Reinforced Soft Actuator" is the result of my own research except as cited in the references. The project report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature :

Name : WONG MIN YEE

Date : 4 JULY 2021

APPROVAL

I hereby declare that I have checked this report entitled "Design and Motion Characterisation of Fibre-Reinforced Soft Actuator" and in my opinion, this project report it complies the partial fulfilment for awarding the award of the degree of Bachelor of Mechatronics Engineering with Honours

Signature : ....

Supervisor Name : ASSOC. PROF. DR. MARIAM BINTI MD GHAZALY

Date : 4 JULY 2021

DEDICATIONS

To my beloved family and friends.

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ABSTRACT

In the recent years, there has been a rise in the need for a solution to the injuries of users caused by conventional rigid actuators. Conventional robots made of moving mechanical parts actuated by hard conventional actuators are unsafe for human. Due to their hard, physical characteristics, they are also hard to be implemented in different environments especially in an unstructured environment. Hence, soft actuators were introduced in order to solve these problems. Soft actuators have a wide range of application, but the problem is to control the motion. The objectives of this project are to design fibre-reinforced soft actuator for linear motion performance, to optimise the design by varying the actuator parameters using FEM Analysis and to characterise and analyse the best design for linear motion performance by evaluating the maximum extension. The soft actuator will only be simulated using the Abaqus software. Liquid silicone will be used as the main material of study for the soft actuator. The soft actuator will have several input pressures to analyse the performance in terms of extension only. The Fibre-reinforced Soft Actuator was designed using the Abaqus FEA software for linear motion performance. The design was optimised using the FEM Analysis and one of the optimised designs was chosen and optimised until the desired output was achieved. The designs were characterised and analysed with pressure from 0 to 0.01MPa. From Original design to R10 design, there is a 27.12% increase in extension. But from R10 to Optimised design, there is a reduction of 9.88%. However, it is still a 17.24% increase from the Original design. R10 design yields the highest extension. But, Optimised design is chosen for the final design as the unwanted bulging in R10 design is significantly reduced. A material with a higher stiffness was recommended for the Sheath. A controller can also be designed to control the elongation of the linear motion. A displacement sensor could be set up to measure the extension of the soft actuator when it is pressurised. The fibre angle could also be varied to analyse the motion output for a better control of the soft actuator.

ABSTRAK

Kebelakangan ini, terdapat peningkatan dalam keperluan sesuatu solusi untuk masalah kecederaan pengguna yang disebabkan oleh penggerak konvensional yang tegar. Robot konvensional yang diperbuat daripada bahan mekanikal yang bergerak dan digerakkan oleh penggerak konvensional yang keras tidak selamat untuk manusia. Oleh kerana sifat fizikalnya yang keras, mereka juga sukar untuk dilaksanakan dalam lingkungan yang berbeza terutama di lingkungan yang tidak terstruktur. Oleh itu, penggerak lembut diperkenalkan untuk menyelesaikan masalah ini. Penggerak lembut mempunyai pelbagai aplikasi, tetapi masalahnya adalah untuk mengawal gerakan lentur. Objektif-objektif projek ini adalah untuk mereka bentuk penggerak lentur yang bertetulang gentian untuk prestasi gerakan linear, dan mengoptimumkan reka bentuk dengan menggubah parameter penggerak menggunakan analisis FEM dan mencirikan dan menganalisis reka bentuk terbaik untuk prestasi gerekan linear dengan menilai pemanjangan maksimum. Penggerak lembut hanya akan disimulasikan menggunakan perisian Abaqus. Silikon cair akan digunakan sebagai bahan utama kajian untuk penggerak lembut. Penggerak lembut akan mempunyai beberapa masukkan tekanan untuk menganalisis prestasi dari segi pemanjangan sahaja. Penggerak lembut gentian bertetulang telah direka menggunakan perisian Abaqus FEA untuk prestasi gerakan linear. Penggerak lembut gentian bertetulang telah direka menggunakan perisian Abaqus FEA untuk prestasi gerakan linear. Reka bentuk dicirikan dan dianalisis dengan tekanan dari 0 hingga 0.01MPa. Dari reka bentuk asal hingga reka bentuk R10, terdapat peningkatan pemanjangan 27.12%. Tetapi dari R10 hingga Reka bentuk yang dioptimumkan, terdapat penurunan sebanyak 9.88%. Walau bagaimanapun, ia masih meningkat 17.24% daripada reka bentuk Asal. Reka bentuk R10 menghasilkan pemanjangan tertinggi. Tetapi, reka bentuk yang dioptimumkan dipilih untuk reka bentuk akhir kerana bonjolan yang tidak diingini dalam reka bentuk R10 dikurangkan dengan ketara. Bahan dengan kekakuan yang lebih tinggi dianjurkan untuk Sarung. Pengawal juga boleh dirancang untuk mengawal pemanjangan pergerakan linear. Sensor perpindahan dapat diatur untuk mengukur pemanjangan penggerak lembut ketika ditekan. Sudut gentian juga dapat diubah untuk menganalisis output gerakan untuk kawalan yang lebih baik dari penggerak lembut.

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LIST OF SYMBOLS AND ABBREVIATIONS

FEA - Finite Element Analysis
FEM - Finite Element Method
DOF - Degrees-of-freedom
SPA - Soft Pneumatic Actuator
PneuNet - Pneumatic Network
mm - millimetre
° - degrees
FR - Fibre-Reinforced

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CHAPTER 1

INTRODUCTION

1.1 Motivation

Hard robots consist of joints that are connected to rigid links and are designed to be stiff so that vibration and deformation of the structure and drivetrain can be omitted in dynamic analysis. Hard nonredundant robots are widely utilised in well-defined settings, for example, in manufacturing where repetitive tasks are carried out continuously in a specified motion with great accuracy. Hard redundant robots, especially hyper-redundant ones, are capable of high mobility when working in uncontrolled settings [1]. In comparison with hard robots, soft robots, like the one shown in Figure 1.1, use various mechanisms to gain dexterity. The benefit of soft robots is the resulting low resistance as the robot compresses a contact point. The risk of damage can be greatly minimised, making soft robots a compelling option for medical uses. The expense for the hyper-redundancy and the comfort contact, however, is the complexity in modelling and control design. There are many factors for the difficulties in control design. The soft robot model is nonlinear and linked. Their models have a greater proportion of expectations and estimations that increases the magnitude of deviations. Additionally, soft robots are underactuated because not every DOF applies to the actuator. Together these features increase the complexity of modelling and control design for robotic applications [1]. In order to realise the soft robot's maximum capabilities, it is important to take all parts into account at the same time or else the component that functions independently may not operate in unison with the rest. Like rigid robots, from a practical perspective, soft robots have components like mechanisms, actuators, sensors, power, and structure. But these various major parts of the soft robot may come from one common physical structure. Conventional rigid robots have always been widely used for a long time. The robot typically uses heavy, rigid actuators together with rigid transmission mechanisms [2]. The mechanical components such as links and joints in a conventional robot allows accurate, fast, complex movements, powerful and repetitive position control operations effectively [3]. The precision and repeatability of these robots make them suitable for both heavy and non-heavy industrial applications [2, 3, 4]. These traditional systems, however, require extensive engineering design processes involving costly materials and accurately manufactured parts that takes time and money to procure, produce, install and transport [4, 5, 6]. In order for the vibration and deformation of the structure and drivetrain to be ignored in dynamic analysis, traditional robots are designed to be rigid [1]. Although conventional actuators like electric motors and internal combustion engines still heavily influences the industry, there has been a rise in demand for a lighter, smaller or faster actuation mechanism [7]. The systems need to be less rigid and more versatile in order to be able to conduct more adaptive and flexible interactions with complex unpredictable environments and to be more compliant with human interactions. [3]. The arising soft robotics discipline seeks to develop robotic systems mainly fabricated from soft polymers that can execute complex motion under different conditions and communicate and adjust to the external surroundings in more secure and preferred manner than the traditional robotic systems constructed from rigid materials without needing high level feedback control methods [4, 8, 9, 10]. The inherent compliance, easy fabrication, and ability to accomplish complicated output movements from simple inputs are what makes soft robotics so popular [11]. The efficiency of the soft robotic systems relies heavily on the efficiency of its actuator. The requirements of soft actuators are the softness and flexibility liken to natural muscles, that conventional actuators are unable to provide [8]. Flexible materials (e.g., polymers, elastomers, and hydrogels) are commonly used to produce soft actuators that leads to a wide potential of soft actuators to interface with humans, animals, handle delicate objects, withstand mechanical challenges and perform complicated movements [4, 12, 13]. The soft material provides another solution to the design process where it is feasible to produce custom actuators on-site quickly and cheaply [4]. Soft robots utilise a number of mechanisms to gain dexterity. The distributed deformation that has a potentially limitless number of degree-of-freedoms (DOF) characterises these soft robots [1, 4]. Some other benefit of soft robots is the resulting low resistance as the robot deforms upon contact with another surface, which can greatly minimise the risk of causing injuries [1]. Nonlinear and coupled soft robot models leads to a larger percentage of assumptions and approximations, which increase the degree of errors [1, 5, 13]. Besides that, soft robots are underactuated, because not all DOF correlates to the actuator [1]. Together, these attributes contribute to a high complexity in both modelling and control architecture for the field of robotics [1]. Although these soft robots are underactuated, soft robots are simple and inexpensive and can accomplish certain functions competently and sometimes outperform them [1, 5].

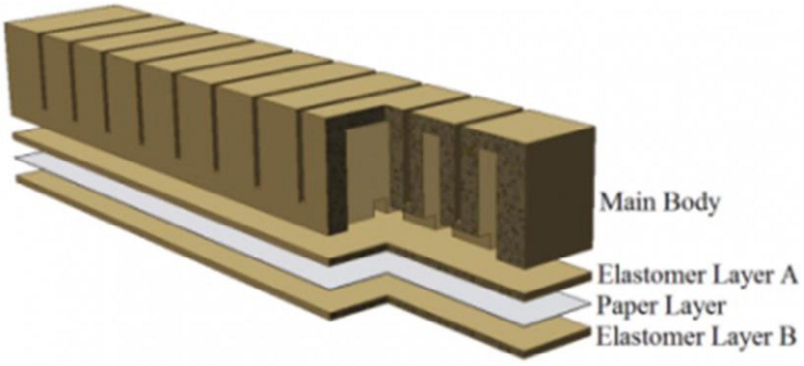


Figure 1.1 Common Soft Actuator (PneuNets Soft Actuator) [14]

1.2 Problem Statement

In the recent years, there has been a rise in the need for a solution to the injuries of users caused by conventional rigid actuators. Conventional robots made of moving mechanical parts actuated by hard conventional actuators are unsafe for human [15]. Conventional Actuators can sustain higher pressure and produce higher output force, speed, precision and accuracy when compared to a soft actuator [15, 16, 17]. But due to its rigid material, it is unsafe for human-machine interactions especially in unstructured environments [15]. Due to the rigidity of conventional actuators, the hard material can pose a threat to humans. Their hard, physical characteristics, they are also hard to be implemented in different environments especially in an unstructured environment [15]. Hence, soft actuators were introduced in order to solve the shortcomings of the conventional actuators [15, 16, 17, 18]. Soft actuators are actuators made of soft flexible materials that can be actuated with methods such as pneumatic actuation that pressurise the internal chambers to change the shape and produce motions such as bending [15, 17, 18]. Therefore, soft actuators are better and safer to utilise in situations that require human-machine interactions [15]. Soft actuators have a wide range of application, but presently, the problem is it is hard to be precisely modelled and to control the motion [19]. Before the fabrication and introduction of sensors and controllers are applied to the soft actuators, the design of the soft actuators must be analysed, optimised and characterised for the output performance to produce the right design for a specific application.

1.3 Objectives

The objectives of this project are:

1. To design fibre-reinforced soft actuator for linear motion performance.
2. To optimise the design by varying the actuator parameters using Finite Element Method (FEM) Analysis.
3. To characterise and analyse the best design for linear motion performance by evaluating the maximum extension.

1.4 Scope

The scopes of this project are:

1. The soft actuator design will be simulated using the Abaqus software.
2. Liquid silicone is (Ecoflex 00-30) is used as the main material of study for the soft actuator.
3. The soft actuator will have several input pressures to analyse the performance in terms of extension only.

CHAPTER 2

LITERATURE REVIEW

2.1 Actuator

Figure 2.1 generalises the classification of a wide range of robots. The hatched area is an empty set [1]. Hard robots consist of joints that are connected to rigid links and are designed to be stiff so that vibration and deformation of the structure and drivetrain can be omitted in dynamic analysis. Hard nonredundant robots are widely utilised in well-defined settings, for example, in manufacturing where repetitive tasks are carried out continuously in a specified motion with great accuracy. Hard redundant robots, especially hyper-redundant ones, are capable of high mobility when working in uncontrolled settings.

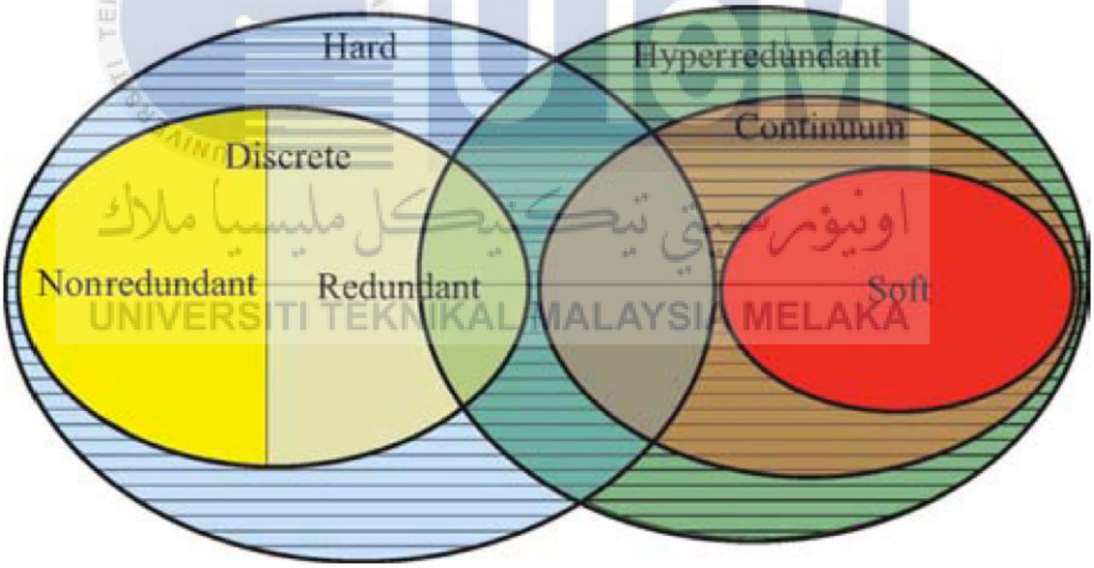
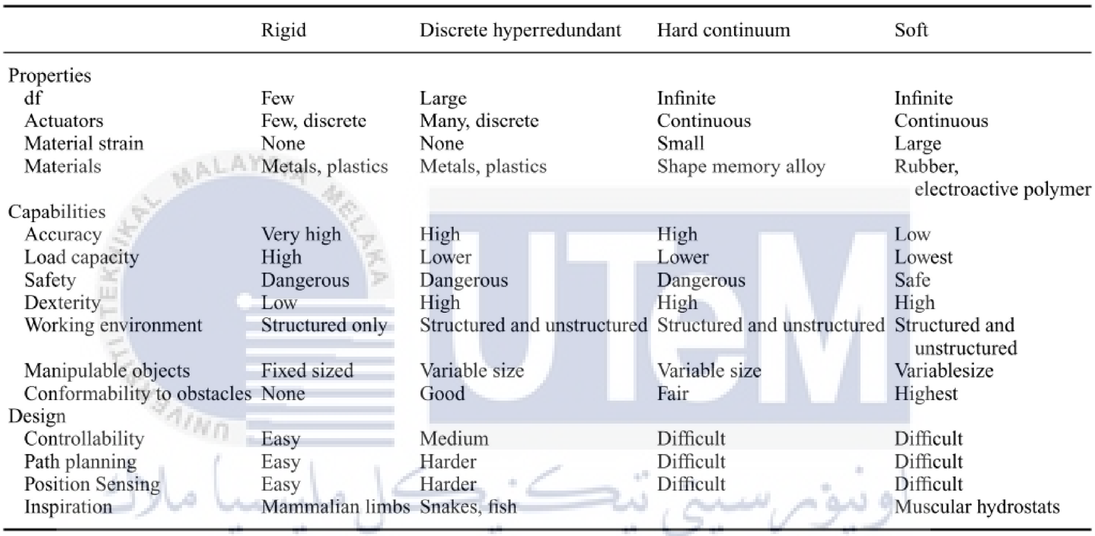


Figure 2.1 Robots Classification Based on Materials and Degree of Freedoms [1]

In comparison with hard robots, soft robots use various mechanisms to gain dexterity. Distributed deformation with a potentially infinite number of degree-of-freedoms (DOF) characterises soft robots such that they can achieve hyper-redundancy in the configuration area. Thus, the robot tip is able to reach every point in the 3D workspace with various shape configurations. Some other benefit of soft robots is the resulting low resistance as the robot compresses a contact point. The risk of damage can be greatly minimised, making soft robots a compelling option for medical uses. The expense for the hyper-redundancy and the comfort contact, however, is the complexity in modelling and control design. The trade-offs among the various kinds of robots [1] are as shown in Figure 2.2. There are many factors for the difficulties in control design. The soft robot model is nonlinear and linked. Their models have a greater proportion of expectations and estimations that increases the magnitude of deviations. Additionally, soft robots are underactuated because not every DOF applies to the actuator. Together these features increase the complexity of modelling and control design for robotic applications.

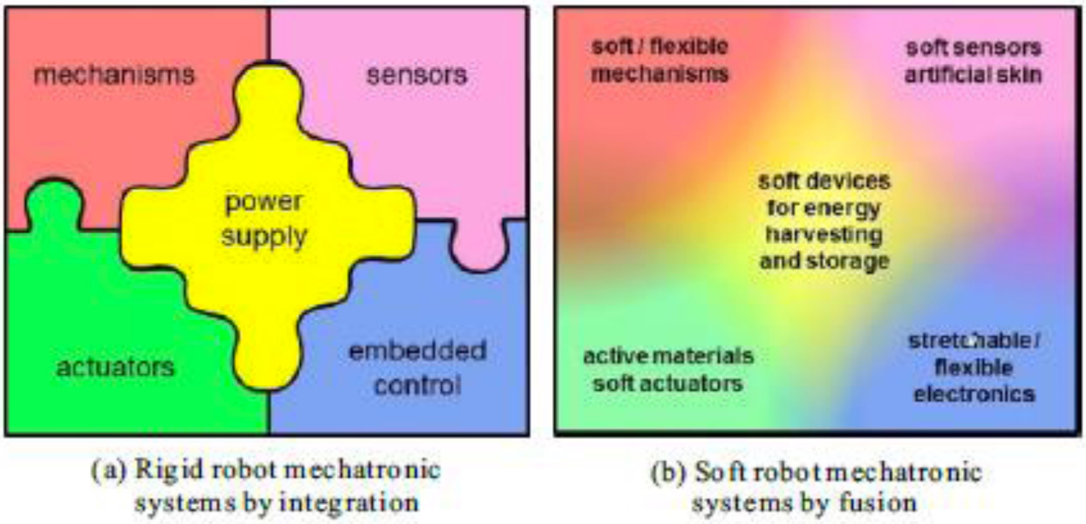


	Rigid	Discrete hyperredundant	Hard continuum	Soft
Properties				
df	Few	Large	Infinite	Infinite
Actuators	Few, discrete	Many, discrete	Continuous	Continuous
Material strain	None	None	Small	Large
Materials	Metals, plastics	Metals, plastics	Shape memory alloy	Rubber, electroactive polymer
Capabilities				
Accuracy	Very high	High	High	Low
Load capacity	High	Lower	Lower	Lowest
Safety	Dangerous	Dangerous	Dangerous	Safe
Dexterity	Low	High	High	High
Working environment	Structured only	Structured and unstructured	Structured and unstructured	Structured and unstructured
Manipulable objects	Fixed sized	Variable size	Variable size	Variablesize
Conformability to obstacles	None	Good	Fair	Highest
Design				
Controllability	Easy	Medium	Difficult	Difficult
Path planning	Easy	Harder	Difficult	Difficult
Position Sensing	Easy	Harder	Difficult	Difficult
Inspiration	Mammalian limbs	Snakes, fish		Muscular hydrostats

Figure 2.2 Characteristics of Different Robot Types [1]

In addition, the mechatronic parts of a soft robot are directly intertwined. In order to realise the soft robot's maximum capabilities, it is important to take all parts into account at the same time or else the component that functions independently may not operate in unison with the rest. Like rigid robots, from a practical perspective, soft robots have components like mechanisms, actuators, sensors, power, and structure. But these various major parts of the soft robot may come from one common physical structure. Figure 2.3 shows the highlights of the differences between rigid and soft robot mechatronic systems [1]. Rigid robots form through integration while soft robots are by fusion. Many soft inflatable robots can be categorised as an intrinsic type, since their actuators not only provide force or torque, but also serve as mechanisms of transmission. Soft inflatable robots can be actuated pneumatically or hydraulically.

The two actuation operates in a similar manner. Pneumatic solutions offer less gravitational effects on soft robots than the hydraulic versions. Plus, it is easier to maintain the former than the latter.



(a) Rigid robot mechatronic systems by integration

(b) Soft robot mechatronic systems by fusion

Figure 2.3 Rigid Robot and Soft Robot Mechatronic Systems [1]

Actuators in the robotic systems transfer energy from any form into motion that controls the interaction of the robotic system and the object or environment [2]. Conventional rigid robots have always been widely used for a long time. The robot typically uses heavy, rigid actuators together with rigid transmission mechanisms. Actuators in these systems are usually made of electromagnetic components and other hard metals [2]. The mechanical components such as links and joints in a conventional robot allows accurate, fast, complex movements, powerful and repetitive position control operations effectively [3]. The precision and repeatability of these robots make them suitable for both heavy and non-heavy industrial applications [2, 3, 4]. These traditional systems, however, require extensive engineering design processes involving costly materials and accurately manufactured parts that takes time and money to procure, produce, install and transport [4, 5, 6]. In order for the vibration and deformation of the structure and drivetrain to be ignored in dynamic analysis, traditional robots are designed to be rigid [1]. Although conventional actuators like electric motors and internal combustion engines still heavily influences the industry, there has been a rise in demand for a lighter, smaller or faster actuation mechanism [7]. The systems need to be less rigid and more versatile in order to be able to conduct